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MEASUREMENT OF TRACER ELEMENTS IN INERTIAL FUSION TARGET FUEL

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Measurement of Tracer Elements in Inertial Fusion Target Fuel*

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Abstract

For some inertial confinement fusion experiments, a tracer impurity element is added to the deuterium-tritium (DT) fuel gas as an aid in diagnosing the implosion conditions. We have developed a general, nondestructive technique for measuring the initial tracer density in an individual fusion target. We take advantage of the fact that beta emission from the tritium excites the tracer characteristic x-ray lines. Using an energy dispersive x-ray detector, we measure the intensity ratio of a tracer x-ray line to the bremsstrahlung background. The ratio is proportional to the tracer density and the inner radius of the target and is independent of other parameters. We have measured argon tracer densities as low as 0.01 atmosphere with an accuracy of $\pm$ 15%.

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Several techniques for measuring the conditions achieved in laser fusion implosions rely on seeding the deuterium-tritium (DT) fuel gas with a tracer element. Imaging the x-ray line emission from a tracer element added to the fuel provides a measurement of the fuel compression.[1] The temperature of the fuel can be calculated from the ratio of emission from different ionization states of tracer atoms. Neutrons produced during the implosion will activate tracer elements, providing a measurement of fuel density.[2] In these experiments it is important to know how much tracer material is present in the target initially. We have developed a general, nondestructive technique for measuring the amount of tracer in an individual fusion target. Our method utilizes the characteristic x rays emitted by the tracer when it is excited by the beta decay of the tritium fuel.

Figure 1 illustrates the measurement principle. When the tritium in the microsphere decays, it gives off a spectrum of electrons, peaked at 2.2 keV, with a mean energy of 5.6 keV and an endpoint energy of 18.6 keV. When these electrons strike the walls of the microsphere, they excite characteristic x-ray lines and also produce a bremsstrahlung continuum. (In a separate application we use this emission from the microsphere wall as a measure of the tritium fill.[3]) When the target fuel contains a tracer element, the tritium electrons also excite any characteristic x-ray lines of the tracer which fall within the energy range of the tritium betas. The ratio of the tracer line intensity to the intensity of the background x rays of the same energy provides a convenient measurement of the amount of tracer. Because the tritium betas have a very short range in the target wall, all of the x rays are produced either inside the fuel region or in the inner few μm of the target wall. The tracer x-ray lines and the background x rays of the same energy are, of course, absorbed exactly the same amount by the rest of the target wall. The line to background ratio is therefore determined only by the amount of tracer gas and the composition of the innermost layer of the target. It is independent of the composition or thickness of the remainder of the wall, the absolute x-ray generation rate, and the counting efficiency.

For typical current fusion targets, only a small fraction of the electrons are absorbed in the fill gas. In this case analysis of the x-ray production is simplified. The tracer x ray production rate, I_t is

$$I_t = N_T R_T \sigma_t \rho_t \bar{\ell}$$

where N_T and R_T are the number of tritium atoms in the microsphere and the tritium decay rate, respectively; σ_t is the cross section for producing the tracer x-ray line by bombardment with the tritium electron spectrum; ρ_t is the density of the tracer gas, and $\bar{\ell}$ is the average path of a tritium electron from its production point to the wall of the microsphere.

Once the tritium betas strike the microsphere wall, they deposit their energy over a very short range (1 - 2 μm). Under the assumption that there is little electron absorption in the fill gas, the rate of x-ray production per unit energy interval is

$$I_B(E) = N_T R_T P_B(E)$$

where $P_B(E)$ is the production coefficient for x rays of energy E from tritium betas which are totally absorbed in the wall material.

The ratio of the tracer line intensity to the background intensity at the same energy, R, is thus

$$R = \frac{I_t}{I_B(E_t)} = \frac{\sigma_t \rho_t \bar{\ell}}{P_B(E_t)}$$

where E_t is the energy of the tracer x-ray line.

By integrating over the fuel volume and over all paths from a decay point to the wall, it is straightforward, though tedious, to show that $\bar{\ell}$ is simply

$$\bar{\ell} = 3/4 \ r_i$$

where r_i is the inner radius of the sphere. We thus have

$$\rho_t = C \frac{R}{r_i}$$

where the constant C contains the production efficiencies and geometrical factor.

Once the calibration constant, C, has been established for a given composition of the inner wall, the method can be used for any target which has the same inner wall material. This is a particularly useful feature, since many different laser targets are made by coating various materials onto a DT filled glass microsphere.

The rate of x ray production in most current targets is small, so an efficient counting system is required in order to avoid unacceptably long counting times. We use a 30 mm^2 Si(Li) detector and position the sample within about 2 mm of the active area. This results in a counting efficiency of about 25% of 4π steradians. With this geometry, counting times of several hours are required for typical targets.

We have calibrated our measurement technique for glass microspheres containing argon as a tracer gas.[4] These microspheres are used as targets in experiments with argon line imaging density measurements.[1] Figure 1 shows a typical spectrum obtained from one of these targets. We use a linear interpolation algorithm to determine the background count rate at the argon k_α line energy (2.96 keV). The ratio of the argon k_α line intensity to background was measured for each of ten microspheres. The microspheres were then crushed individually in a very sensitive mass spectrometer and the amount of argon in each was measured.[5] The results of this comparison are shown in Table 1. The measured microspheres represent a variety of different sizes, DT fill levels, wall thicknesses, and wall compositions, but within the errors of the experiment, the calibration constant is the same for all of them.

The calibration constant, 6.4 eV $\cdot$ mole/m^2, is valid for any target having a borosilicate glass microsphere inner layer and for any x-ray counter and counting geometry. Also, this constant is useful for a wider range of inner wall materials than might be initially supposed. The background under the argon line is due to bremsstrahlung, and the total bremsstrahlung production from stopping an electron of a given energy is not a strong function of the wall material. We have found, for example, that for microspheres containing 25 molar percent lead (60 weight percent), the bremsstrahlung in the 3 keV region is increased less than a factor of two. Using the above calibration will thus give a rough idea of the amount of argon in a microsphere, even for a vastly different composition.

This technique is applicable to many different tracer materials. The only requirement being that the tracer have a characteristic x-ray line which will be excited by the tritium and can penetrate the target wall. Once calibrated for a given tracer and a given inner wall, the measurement is independent of most target and counting parameters. It provides a convenient method for measuring the amount of tracer gas in a DT filled microsphere.

References

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Captions

Figure 1 Tritium beta decay excites characteristic x-ray lines of tracer elements in the fuel. The ratio of this line intensity to the bremstrahlung background provides a convenient measure of the tracer density.

Table I. Calibration data for argon tracer in fusion targets with a borosilicate glass pusher

Sample #	Inner radius μm	Glass wall thickness μm	CF coating thickness μm	Argon density $\frac{moles}{m^3}$	Ar K_α/Brems ratio R MeV^{-1}	Calib const $\frac{eV \cdot mole}{m^2}$
1	76	2.3	9.0	2.36	26.5	6.76
2	65	4.7	0	3.95	32.1	8.00
3	64	5.0	0	5.33	45.1	7.58
4	63	5.3	0	7.06	55.3	8.00
5	71	3.4	17.1	0.22	<1.5	—
6	75	4.5	16.5	0.20	<1.5	—
7	68	3.0	12.2	4.38	57.3	5.21
8	69	5.3	11.3	3.28	37.1	6.10
9	75	3.5	13.1	1.17	17.1	5.13
10	82	3.4	0	4.34	62.1	5.75

Average 6.37
Average deviation 0.97 = 15%

MICROSPHERE FILL MEASUREMENTS

Total no. of x-rays is a measure of the tritium fill
Ratio of Ar K_α to 3 keV background is a measure of the Ar content

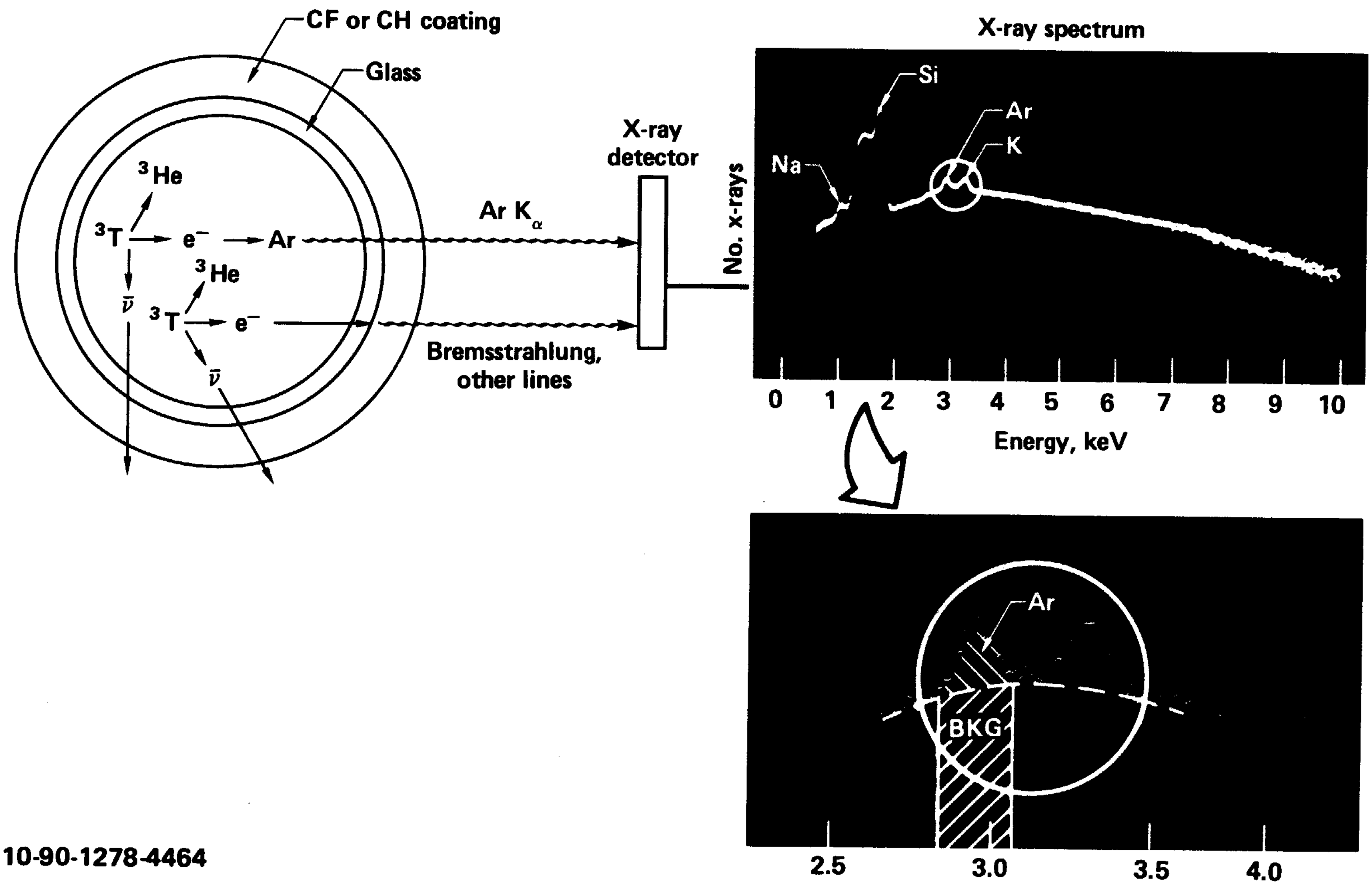

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Figure 1